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Analytical modelling of the formation temperature stabilization during the borehole shut-in period

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Abstract

The problem of formation temperature stabilization during the shut-in period is solved analytically by the approximate generalized integral-balance method. The model accounts for the thermal history of the borehole exploitation, which may include a finite number of circulation and shut-in periods, and different flow regimes during circulation periods. The latter is determined by the temperatures of the circulating fluid and different Biot numbers that depend on intensity of the heat transfer on the bore-face. Normally the temperature fields in the well and surrounding rocks are calculated numerically by the finite-difference and finite-element methods or analytically, by applying the Laplace-transform method. Formulae, analytically obtained by Laplace transform, are rather bulky and require tedious non-trivial numerical evaluations. Moreover, in previous research the heat interactions of the circulating fluid with formation were treated under the condition of constant bore-face temperatures. In the present study the temperature field in the formation disturbed by the heat flow from the borehole is modelled by the heat conduction equation and thermal interaction of the circulating fluid with formation is approximated by the Newton relationship on the bore-face. The problem for circulation and shut-in periods is solved analytically using the heat balance integral method, where the radius of thermal influence, which defines the thermally disturbed domain, is a function of time, which satisfies the algebraic equation. Within this method, the approximate solution of the heat conduction problem is sought in the form of a finite sum of functions which belong to a complete set of the linearly independent functions defined on the finite interval bounded by the radius of thermal influence and satisfy the homogeneous boundary condition on the bore-face. It can be proved theoretically that the approximate solution found by this method converges to the exact one. Numerical results illustrate quite good agreement between the approximate and exact solutions. As a result of its simplicity and accuracy, the derived solution is convenient for geophysical practitioners and can be readily used, for instance, for predicting equilibrium formation temperatures.

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Keywords

Fluid circulation, Integral-balance method, Rock formation temperature, Shut-in period, Thermal stabilization